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THE BOD5/DO RATIO. A NEW ANALYTICAL TOOL FOR WATER QUALITY EVALUATION

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THE BOD_5/DO RATIO

A NEW ANALYTICAL TOOL FOR WATER QUALITY EVALUATION

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Table of Contents

Chapter		Page
I	Introduction	1
II	BOD evaluation	2
III	DO evaluation	3
IV	Theory and Methodology	4
	A. Theory	4
	B. Methodology	5
V.	Examples of BOD_5/DO ratio in practice	8
	A. Cleanwater stream - Jackson River	8
	B. Clean water stream - White Oak Creek	11
	C. Partially degraded stream - Susquehanna River	12
	D. Partially degraded stream - Missouri River	14
	E. Degraded stream - Potomac River	15
	F. Severely graded streams	16
	G. Freshwater/esturine streams - Delaware River	17
	H. Specialized uses	19
VI.	Stream classification using BOD_5/DO ratio	19
VII.	Computer program (STORET) for processing BOD_5/DO data	21
Summary		22

Appendix

A. Computer program listings

1. BOD_5/DO ratio

2. Statistical analysis

I. Introduction

The basic definition of the biochemical oxygen demand (BOD) is usually given as the amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic conditions (1). This determination of BOD has been, and continues to be, widely used to evaluate the oxygen-consuming strength of municipal and industrial wastes being discharged into receiving streams. Dissolved oxygen (D.O.) in stream waters is a measure of the oxygen available for bacterial consumption in stabilizing organic material. These two parameters are used by Sanitary Engineers in determining oxygen-sag curves, Deoxygenation and Reaeration rates as well as the ultimate oxygen consumption load imposed on the stream.

In the past, the object of such analyses has been to ascertain the various rate functions of the BOD and D.O. curves. This paper, however, departs from such an approach and simply uses the two parameters to determine the ratio between them at each sample site and for each sample taken. This method is dependent upon two basic premises. These are: 1) That the BOD test at the sample station is reproducible within the normal limits of error for the test and free from interfering substances and 2) That the

1. Sawyer, Clair N., Chemistry for Sanitary Engineers, McGraw-Hill, New York, 1960 p.270

period of record extends across several annual cycles on a monthly sampling frequency at a minimum.

When a sufficient amount of data points have been accumulated, then a linear trend for the data set can be established. If this linear trend is horizontal (m=o) then the system is maintaining itself as a steady state condition of dynamic equilibrium. A condition of $y=(mx+b)$ where $m > o$ is unacceptable in that it demonstrates a steadily degrading water quality condition in the stream. A secondary method of analyzing the data is to examine the fluctuations about the mean on both a daily and annual basis. If the standard deviation value is small, then the stream is demonstrating a normal situation. If these values are large, then the stream is "nervous" indicating potentially unfavorable conditions in the stream at the sample station.

This paper will demonstrate the postulations given above and illustrate the various situations actually occurring at stream stations across the conterminous United States.

II. BOD Evaluation

The 5-day BOD test (BOD_5) represents that amount of oxygen demand exerted by biochemical activity over a 5-day time span. This test is not fool proof and is subject to numerous sources of

error. An attempt to rely too heavily upon the BOD values alone must not be made. Instead, the BOD_5 value should be used in comparison with some other parameter; in this case the D.O. value.

Because the kinetics of the BOD reaction are such that approximately 70 to 80 percent of the ultimate BOD load value is obtained in 5 days, it is logical to assume that a "safe" ultimate BOD value in normal streams would be a value less than the D.O. content. Therefore, a safe ratio between the BOD_5 value and the D.O. value measured at the same time at the same station should be not more than 0.3 for normal streams. Such a value would allow for the additional load imposed by chemical oxygen demand as well as the added load from nitrification and still remain less than the amount of D.O. present. Put in another way, it means that the total debt (BOD loading) remains less than the reserve (D.O. content) and one cannot, therefore, be "over drawn at the bank".

III. D.O. Evaluation

The dissolved oxygen (D.O.) content of any given stream is the sum of a large number of interacting variables. Some of these are inorganic, mechanical factors such as barometric pressure, temperature, channel geometry and flow velocity. Others are either directly organic as in the case of algal O_2 production or indirectly organic as in the case of nutrients such as vitamins, nitrates, phosphates and trace elements.

Streams with steep gradients, high flow velocities, turbulent flow and sediment-free, cold waters can be expected to assimilate a greater loading of BOD than sluggish, meandering, low velocity warm water streams. The level of nutrient is very important because excessive nutrients allows an exaggerated fluctuation of the diurnal D.O. curve. Such a condition is seen in the Tamiami Trail area of Florida (2) where the D.O. concentration drops to approximately zero each night under the influence of algal respiration and rises to super-saturated values under energetic photosynthetic activity of the plant community during the following day. Under these circumstances fishkills can occur even under "normal" stream conditions.

IV. Theory and Methodology

A. Theory

The BOD_5 test should not be used in the exclusion of other supporting tests such as total organic carbon (TOC) or chemical oxygen demand (COD) due to the number of error sources inherent in the BOD method. For the purposes of this paper, however, the most useful supporting tests for analytical purposes appear to be total chlorophyll, total nitrates and total phosphates. If long-term trends are required, the ratio of BOD_5/DO alone may be plotted without need to refine the stream ecological reactions further.

2. Little, John A., Robert F. Schneider and Bobby J. Carroll, A Synoptic Survey of the Limnological Characteristics of the Big Cypress Swamp, Florida, FWQA, Southeast Region, May 1970.

STORET, the Environmental Protection Agency's data storage computer system, contains a large mass of data bits acquired at various stations across the country. In order to evaluate the validity of the BOD_5/DO ratio as an indicator to stream health in all types of streams, a computer program can be written to retrieve BOD_5 and DO data from each sample station, then to divide D.O. into BOD_5 and print the result. In addition, a supplementary statistical linear regression subroutine program is available to determine the slope of the linear trend of a moving average plot. A value of $m \leq o$ in the expression $y=mx+b$ means the stream is either maintaining a dynamic equilibrium ($m=o$) or becoming cleaner $m<o$. If the stream is being degraded, then the slope of the linear trend is positive and m will be greater than o.

Therefore, by means of the simple ratio test of BOD_5 over DO, it is possible to obtain an approximation of the actual state of ecological vigor of the stream. If the monitoring of this ratio is extended over a time span covering several years, then the slope of the linear trend will define the success or failure of any pollution-abatement programs underway in the basin.

B. Methodology

During the course of a normal day with optimum summer incident solar radiation, the photosynthetic activity of the

plankton and rooted aquatic communities generates a diurnal dissolved oxygen fluctation. The magnitude of the fluctuation is dependent upon temperature, available nutrients, solar radiation and type of stream flow. If the stream contains excess nutrients and is sluggish, then the dissolved oxygen curve varies greatly between the depressed D.O. levels seen during the evening hours and the supersaturated conditions occurring during peak daylight production (Figure 1). The condition for a normal, clean stream is one of much less daily fluctuation of the dissolved oxygen curve as also shown in Figure 1. Care must be exercised, however, in the analyses of curves to account for the fluctuations in the insolation rate caused by cloud cover.

The production of supersaturated dissolved oxygen conditions also indicates large amounts of biodegradable material being generated. This biomass, generally algal material, imposes a biologically-derived oxygen demand upon the stream. Therefore, samples taken during winter low temperature conditions should reflect biological activity minima. If the BOD_5/DO ratio diminishes only slightly during winter months, then the greater proportion of the observed BOD loading can be attributed to either man-made or non-point source pollution. Under extreme conditions of very low temperatures and frozen ground, the observed BOD loading will be almost entirely man-made because input from all other sources has been reduced essentially to a minimum. Conversely, a large summer/winter BOD_5/DO fluctuation would indicate the major portion of the BOD load to be derived from biological activity and the problem in the stream is one of the excess nutrients rather than

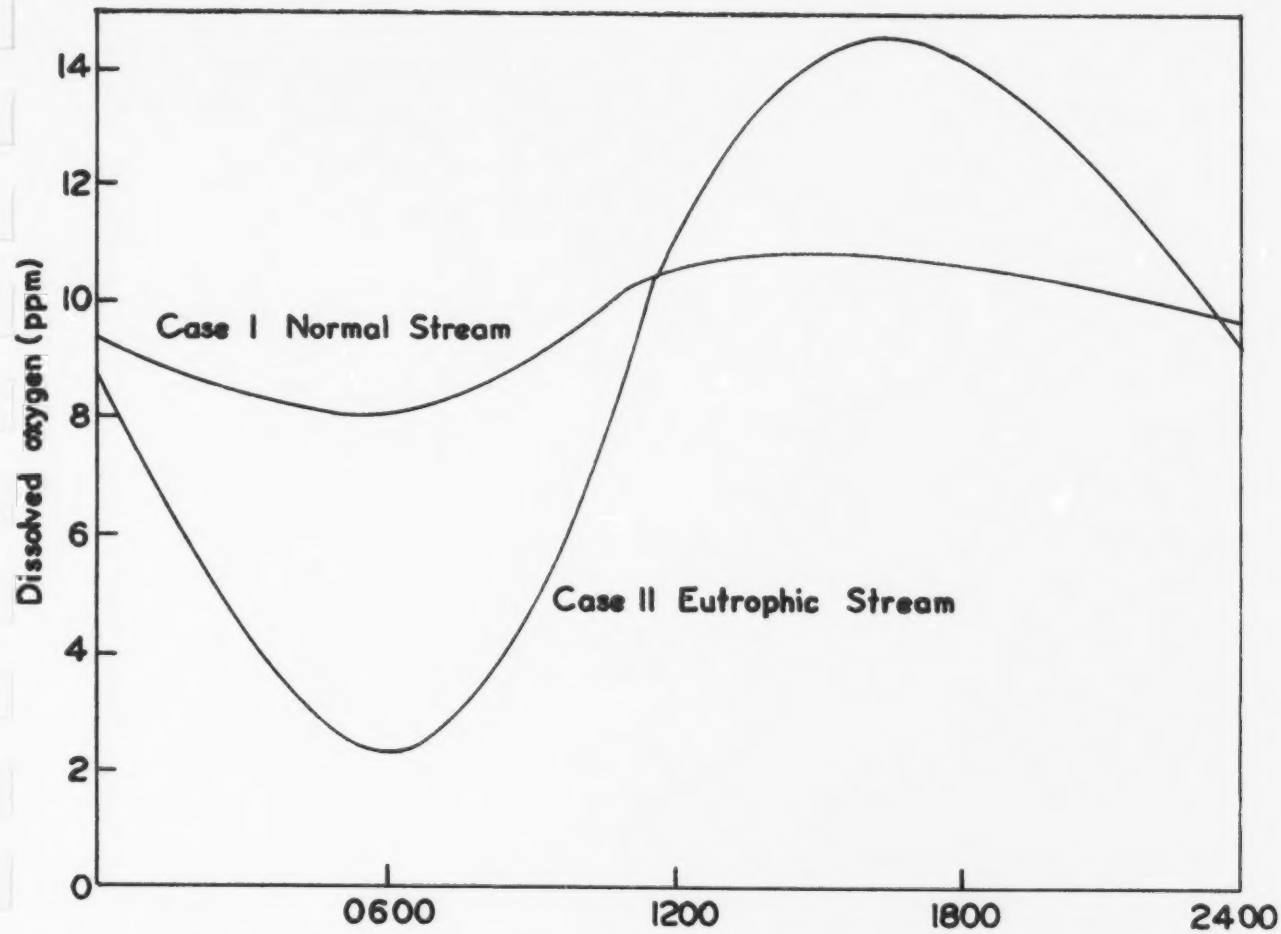

FIGURE I : Diurnal oxygen fluctuation curves for normal versus eutrophic stream conditions

municipal or industrial pollution. This supposition may be verified by analyses for nutrients and chlorophyll. Lastly, there will be a period when the BOD_5/DO ratio will increase toward unity thus showing the normal upsurge of algal activity which occurs each spring. A smaller peak may be detected in late summer for the same reason. Figure 2 illustrates the conditions described above. In addition, a stream which has been, and continues to be degraded will show only minimal seasonal variation in the BOD_5/DO ratio but will show marked peaks and troughs reflecting the effect of the influx of cleaner overland runoff from precipitation.

If a stream exhibits a BOD_5/DO ratio which is that of a clean water system but which lacks normal bio-logical assemblages, then the problem may be attributable to toxicity problems from heavy metals and/or organic chemicals. The situation where the BOD_5/DO ratio occasionally drops to a very low value ($BOD_5/DO \leq 0.03$) seems to be due to suppression of the K_1 rate which is, in turn, related to the inhibiting action of tannins and lignins. These factors present special problems in assessing a stream BOD_5 value and tests for such materials should be performed during the early spring and late fall to insure that a localized concentration of such material (runoff from plant and tree litter) does not interfere with the BOD_5 test. An examination of the industrial discharges in a given stream basin will readily identify tannins and lignins

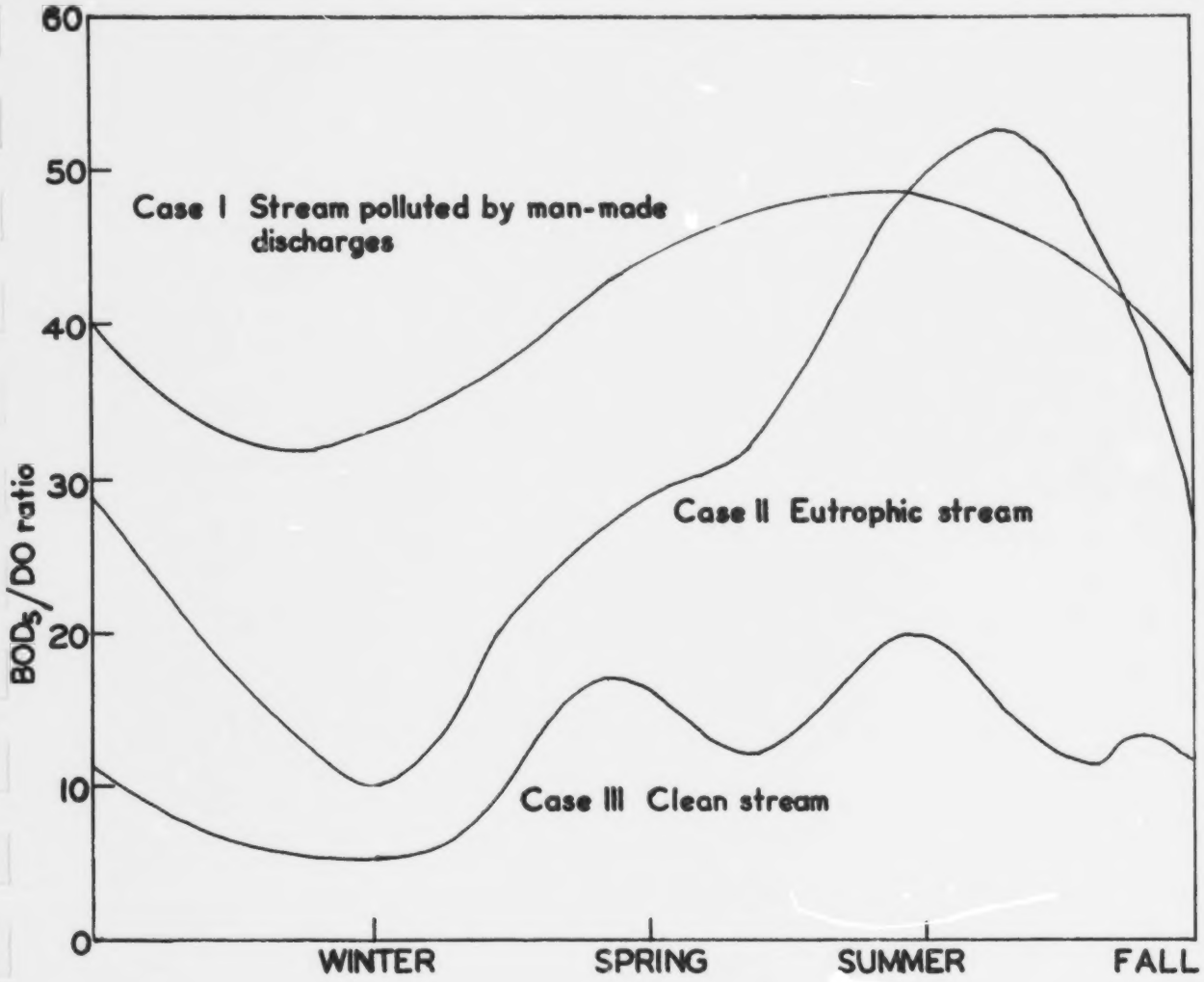

FIGURE 2 : Theoretical annual stream curves plotted from BOD_5/DO ratios

from such man-produced sources as pulp and paper mills.

V. Example of the BOD_5/DO ratio in practice

A. Clean Water Stream-Jackson River above Covington, Virginia

This stream rises in a remote wooded area of the Virginia-West Virginia boundary some 80 miles west of Charlottesville, Virginia near Hot Springs, Virginia (Figure 3). The area is undeveloped with a population density between 6 and 10 persons per square mile. These conditions present an opportunity to observe a clean-water stream system responding to naturally occurring seasonal changes.

During 1971 and 1972, water samples were taken on a monthly basis on the Jackson River above Covington, Virginia. These samples, taken for a pre-impoundment water quality survey, were analyzed for BOD_5 and DO plus other water quality parameters. A summary of the range of BOD_5/DO ratio data for the various stations is shown on Table 1. Preparation of the final report for this survey revealed that there seemed to be a general correlation between the BOD_5/DO ratio at each station throughout the period of study. The attempt to explain this apparent sameness led to the investigation of the ratio in other areas of the country and has culminated in the preparation of this report.

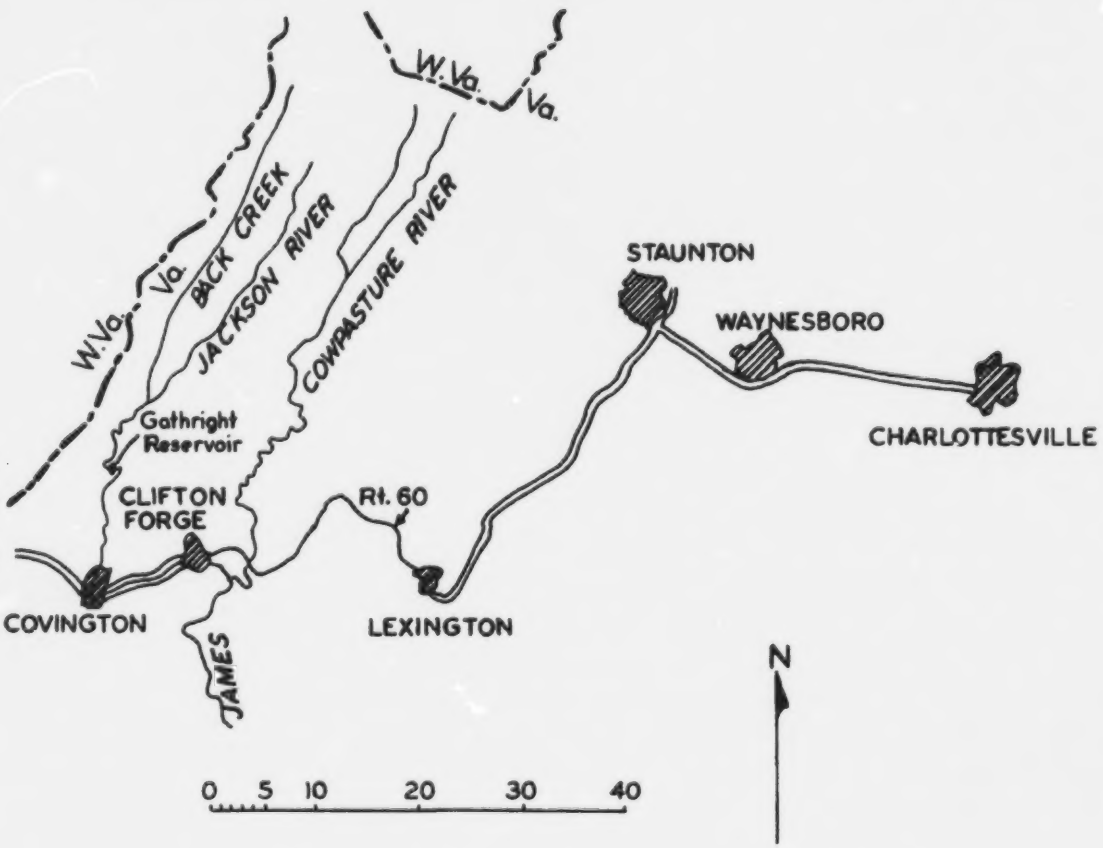

FIGURE 3: Location map, Gathright Reservoir
Jackson River, Virginia

Table 1. Jackson River BOD_5/DO ratios above Covington, Virginia

	Back Creek nr. Mt. Grover, Va.			Jackson River nr Bacova, Va.			Jackson River @ Kelly Bridge			Jackson River @ Natural Wells, Va.			Cedar Creek nr Callison Va.		
	BOD_5	DO	RATIO	BOD_5	DO	RATIO	BOD_5	DO	RATIO	BOD_5	DO	RATIO	BOD_5	DO	RATIO
7/8/71	4.5	8.8	0.511	1.3	9.3	0.140	1.3	9.5	0.137	1.0	10.3	0.097	--	--	--
10/6/71	1	9.1	0.110	1	9.4	0.106	2	8.9	0.225	1	9.6	0.104	1	10.4	0.096
11/18/71	1.1	11.4	0.096	1.3	11.5	0.113	2.8	11.0	0.255	1.2	11.3	0.106	1.1	13.6	0.080
12/13/71	0.8	10.9	0.073	1.4	11.0	0.127	0.8	11.0	0.073	1.2	11.3	0.106	0.8	11.0	0.072
2/24/72	1	11.2	0.089	1	12.3	0.081	1	12.4	0.081	4	12.7	0.315	1	12.1	0.082
4/6/72	--	10.8	--	--	11.8	--	--	10.9	--	--	12.2	--	--	12.4	--
5/4/72	1	9.7	0.103	1	9.2	0.109	1	9.3	0.108	1	9.2	0.109	1	10.1	0.099
6/8/72	1	8.5	0.118	1	9.7	0.103	1	8.8	0.114	1	9.4	0.107	1	10.7	0.093
8/1/72	1	9.5	0.105	1	9.3	0.042	1	9.5	0.105	1	9.3	0.108	1	9.5	0.105
9/8/72	1	9.2	0.109	1	9.7	0.103	1	9.1	0.110	1	9.3	0.108	1	10.2	0.098

Perhaps the fundamental consideration of water quality changes along a river course is to reflect that the observed water quality at any given point is the sum total of all of the changes and influences acting on that stream from the headwaters to the point of sample collection. These influences may be naturally occurring factors such as topography, vegatation, soil cover, bedrock, rainfall, temperature, and stream geometry. Man-induced changes are concerned with farming practices, suburban development, highway construction, forest work, and industrial activity. The stream water quality of any given stream is, at its headwater source, generally free from pollution and contains a very low to non-existant quantity of D.O. (ground water is essentially lacking in dissolved oxygen). As the water flows downstream under the influences of gravity, changes begin to occur. Such changes are related to bedrock minerals, soil cover, foliage and channel geometry. Organisms grow and die in these waters thereby adding and subtracting oxygen, carbon dioxide and nutrient materials in an endless ecological cycle. Because most streams flow continuously, these changes become cumulative with time and each point along the stream has its own more or less unique biochemical water quality make-up. Further, because nutrients are being continually swept downstream by the flowing water, a stream is generally nutrient deficient unless large inputs of nutrients are derived from man-made

sources such as sewage outfalls or non-point source runoff. When the stream gradient diminishes and stream velocity decreases, then conditions tend to become more unstable because of the reduced self-purification potential, and finally, in estuaries, there may be a build up of nutrients and an increase in ecological diversity.

Therefore, a stream segment in a remote, thinly-populated area should be carrying minimum BOD material and maximum dissolved oxygen. The Jackson River fits such criteria and an examination of the BOD_5/DO ratio for all stations reveals a ratio of about 1:10. This ratio seems to be about the normal range for clean mountain streams in the Blue Ridge area with the summer ratios being higher than the winter values. Further, because the stream is clean and pollution-free, the deviations of any given sample from the 0.100 level are generally minimal. This reflects a situation where overland runoff from rainfall is carrying essentially the same BOD concentration as those waters in the receiving stream. Under circumstances such as these, no dilution of BOD concentration occurs in the stream subsequent to a rainfall event and the BOD_5/DO concentration remains close to the 0.100 level over most of the year. Further, because a clean stream carries only a limited quantity of nutrients, no sharp upsurge of algal growth occurs

in the spring. This condition results in little, if any, fluctuation in the BOD_5/DO ratio over the period when algal blooms could occur.

B. Clean water stream in farming area-White Oak Creek, N. C.

White Oak Creek near Bells, North Carolina is a small tributary to the New Hope River which is, in turn, a tributary to the Haw River. The area drained by the White Oak is essentially open agricultural land with no present industrial or municipal discharges above the point of sampling (Fig 4). Water quality data indicate the stream is enriched in nutrients from agricultural sources and this enrichment allows upsurges in algal populations from time to time. A study made for the US Army Corps of Engineers prior to the construction of the New Hope Reservoir revealed that this stream, although receiving no direct effluent from either municipal or industrial sources, still exhibited dissolved oxygen stress from time to time. This stress was observed to coincide with a rise in chlorophyll and turbidity values along with a marked decrease in nutrient values under the influence of a rapidly expanding algal population. Because of this algal upsurge, the BOD_5/DO fluctuation for this stream differs from that observed for the Jackson River in the previous section. The White Oak BOD_5/DO trace seems to approximate the curve shown in Figure 2 for a eutrophic stream but the fluctuations shown are more extreme

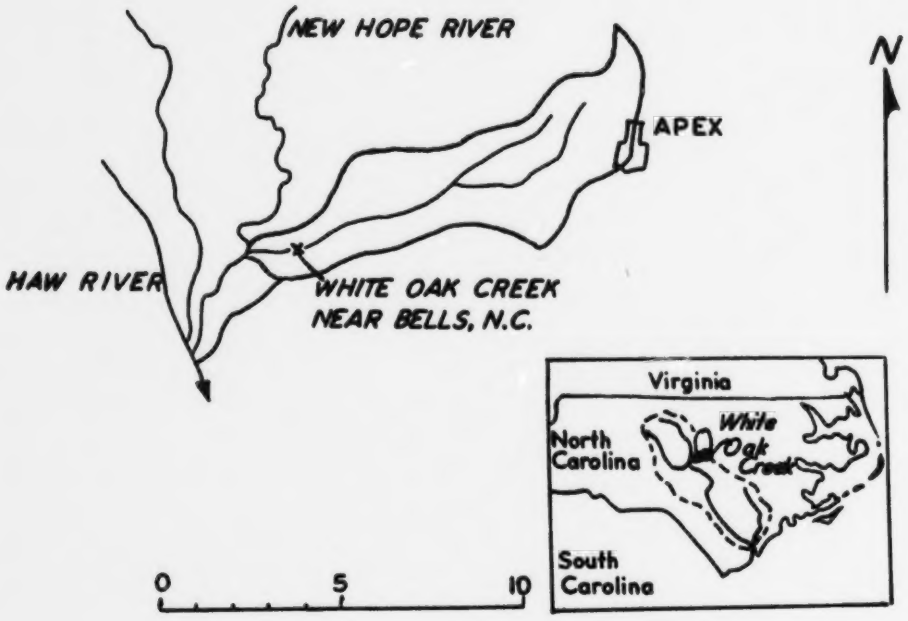

FIGURE 4: Location map, White Oak Creek near Bells, North Carolina

(Figure 5). If a condition such as shown in Figure 5 is allowed to progress in slowly moving water, a situation arises where the oxygen content of the water is supersaturated during daylight hours but nearly depleted under strong respiratory action during the night. Examples of this type of reaction are observed in the Florida Everglades and would be the case in White Oak Creek were this stream impounded for any reason.

Because there is an active current in the White Oak, the upsurge of algae only occurs during the early summer when conditions reach optimum levels of reproduction, allowing the population of algae to maintain itself in spite of being continually swept downstream. The BOD_5/DO ratio in White Oak Creek was observed to fluctuate over a wide range of values and the low values recorded in early 1968 and 1969 (winter conditions) indicate that the high ratios of the summer months are due to algae activity rather than a constant base line of municipal or industrial BOD loading.

C. Partially degraded stream receiving municipal effluents from upstream sources (low sediment yield area)

The main stem Susquehanna River at Berwick, Pennsylvania is an example of a stream partially degraded by municipal effluents from upstream sources; in this case from the Wyoming Valley populations

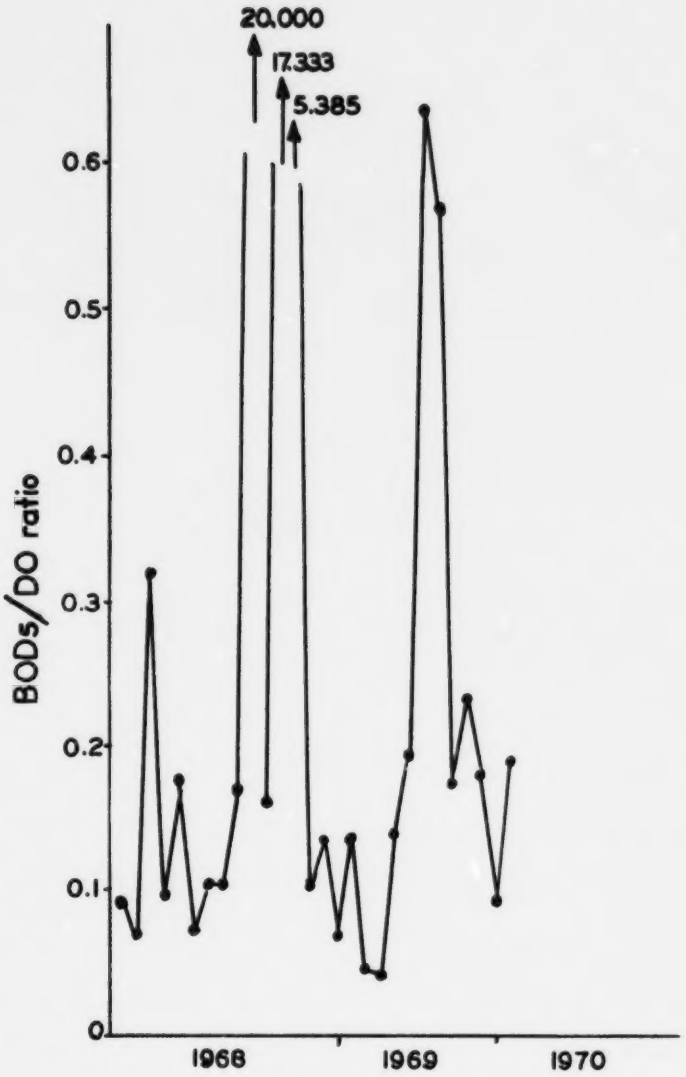

FIGURE 5: BODs/DO fluctuations at White Oak Creek at Bells, North Carolina

centers of Scranton and Wilkes-Barre, Pennsylvania (Figure 6). The Susquehanna River at Berwick also contains contamination from acid mine drainage but this effect does not modify appreciably the BOD_5/DO ratio observed. In addition, these data shown in Figure 7 extend through the period of maximum flood imposed by Hurricane Agnes rains. The data shown in Figure 7 were taken at weekly intervals for inclusion in an Environmental Impact Statement on the Pennsylvania Power and Light Company nuclear generating plant at Berwick. The effect of the flooding was to render the Wilkes-Barre sanitary treatment plant inoperative and the effluent to be discharged into the river without treatment save for chlorination. The peaks observed in September and November 1971, prior to the flooding may be due to periods of maintenance and/or poor operation on the upstream plants. These peaks may also be due to flushing of the bed load by higher flows runoff. In the case of the Susquehanna River, the ratio of effluent to stream flow is small enough to assign the fluctuations observed to the effect of scouring bedload, rather than to treatment plant effluents, even if the effluent is essentially untreated following plant shut down. The case for BOD loading increases from overland runoff is strengthened by the observation that large volumes of water create the illusion of a clean stream (note the precipitous drop in the BOD_5/DO ratio

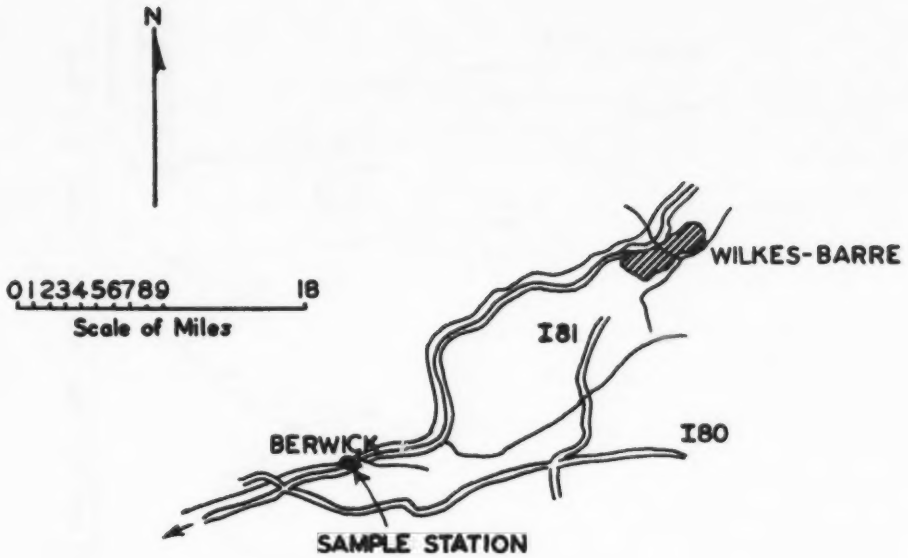

FIGURE 6: Location map, Susquehanna River near Berwick, Pennsylvania

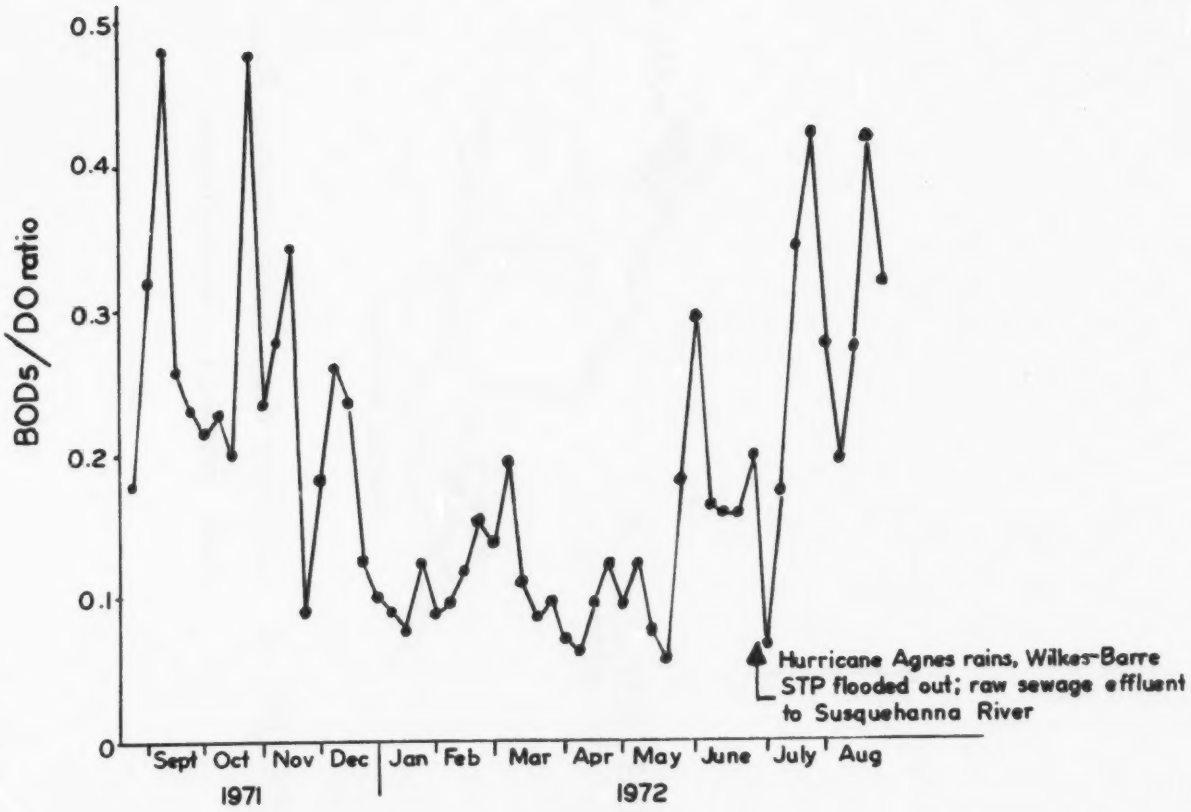

FIGURE 7: BODs/DO ratio for Susquehanna River at Barwick, Pennsylvania

subsequent to the influx of Hurricane Agnes rains as shown in Figure 7). Further, a partially degraded stream seems to be much more sensitive to this type of condition than a clean stream as shown by the narrow range of fluctuation in the Jackson River in Case A.

Case D. Partially degraded stream receiving municipal effluents from upstream sources (high sediment yield area)

The Missouri River at Missouri City, Missouri is an example of a stream receiving municipal and industrial effluents as well as large amounts of sediment from eroding upstream areas. Such a stream does not support expected algal concentrations for the nutrient levels available due to suppression from both organic (sewage) and inorganic (industrial effluents and silt) sources. In the case of silts, however, the turbulence of the flow would allow vertical mixing with the net result that the stream plankton would achieve a steady-state production rate at some reduced volume proportional to the concentration of the sediment present. This net effect is to show mainly the municipal, industrial and non-point source effluent BOD loading with a lesser loading input from the plankton community. The sampling station (Figure 8) is located downstream from the Kansas City area and shows the very slight downward trend of the over-all trace of the BOD_5/DO curve.

FIGURE 8: Location map, Missouri River at Kansas City, Missouri

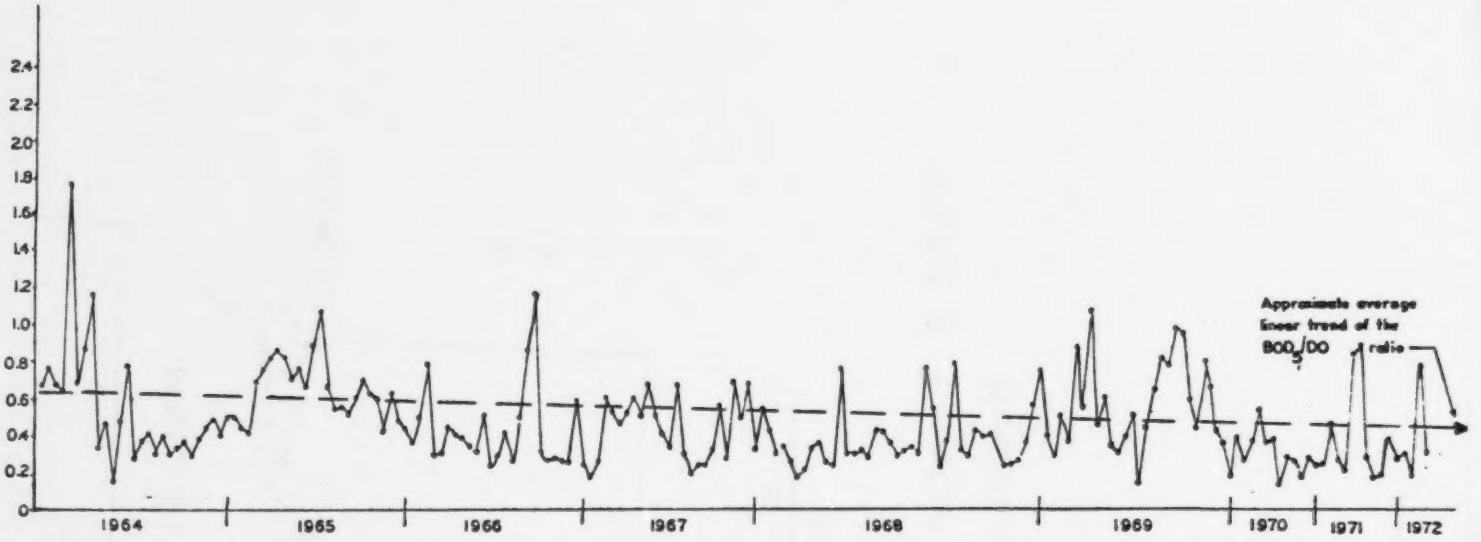

FIGURE 9: BODs/DO ratio trace for Missouri River, Missouri City, Missouri

Such a trend is indicative of successful environmental clean-up efforts, even though the total amount of ratio reduction is quite small (Figure 9).

Case E. Degraded stream draining low sediment yield area

The Potomac River at Great Falls, Maryland (Figure 10) is an example of a stream receiving municipal and industrial effluents, from upstream sources, in quantities sufficient to cause a general and continuing deterioration in the water quality at the observation station. Much attention has been given to clean-up efforts of the Potomac River water quality in the past but the stream water remains in very poor condition (Figure 11). The trace of the BOD_5/DO ratio indicates a deteriorating condition with regards to water quality since early 1968. Some improvement was noted in 1970 but this gain was lost in 1971 with a return to unstable, oscillating ratios.

However, an examination of the ratio trace indicates a strong influence of BOD loading from plankton and rooted aquatics upstream of the sample site due to optimum available nutrients. This premise is based upon the climb toward unity shown during the actively growing period which occurs through the warm-water summer months. When cooler conditions prevail, the biological activity declines and the apparent ratio approaches that observed for clean

FIGURE 10: Location map, Great Falls Potomac River near Washington, D.C.

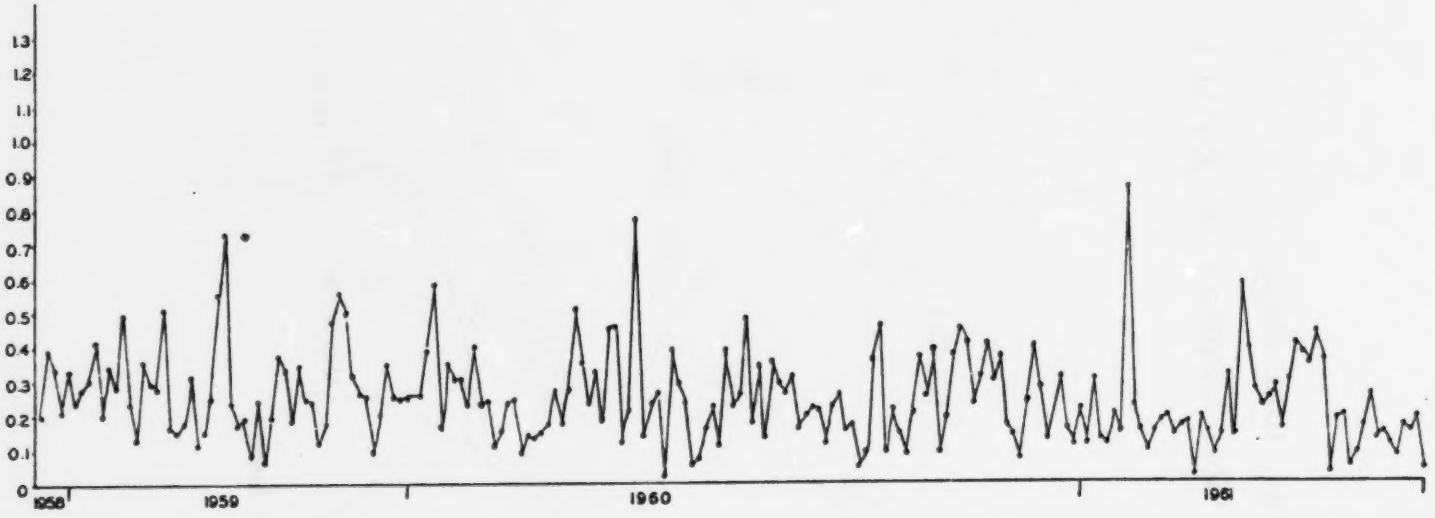

FIGURE 11: BODs/DO ratio trace, Great Falls Potomac River near Washington, D.C.

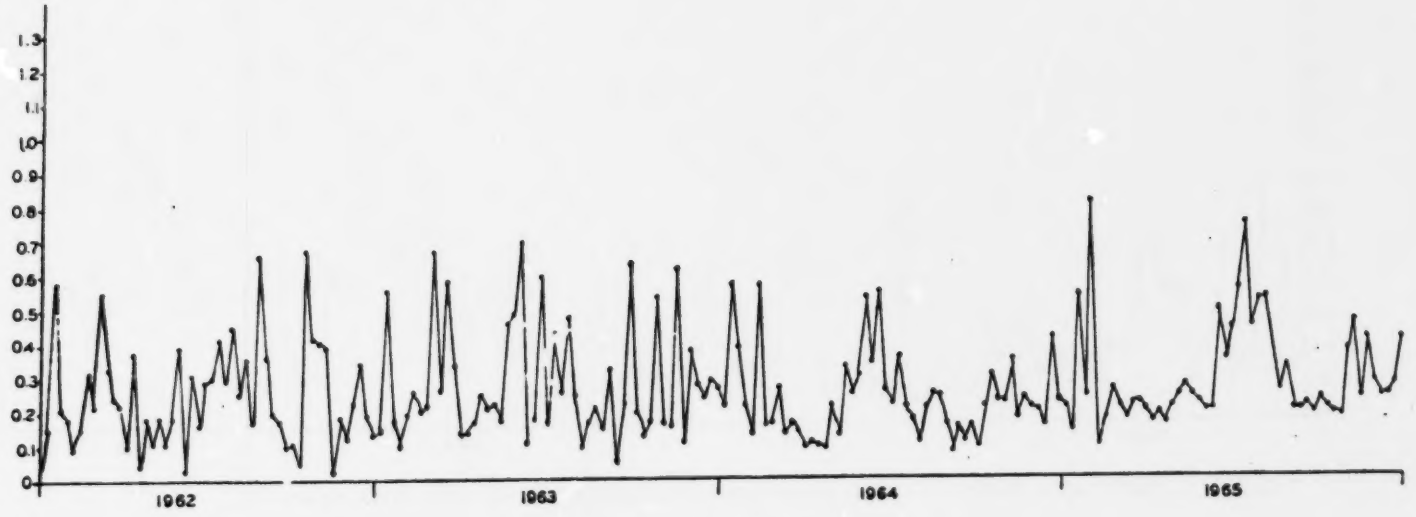

FIGURE II (continued): BODs/DO ratio trace, Great Falls Potomac River near Washington, D.C.

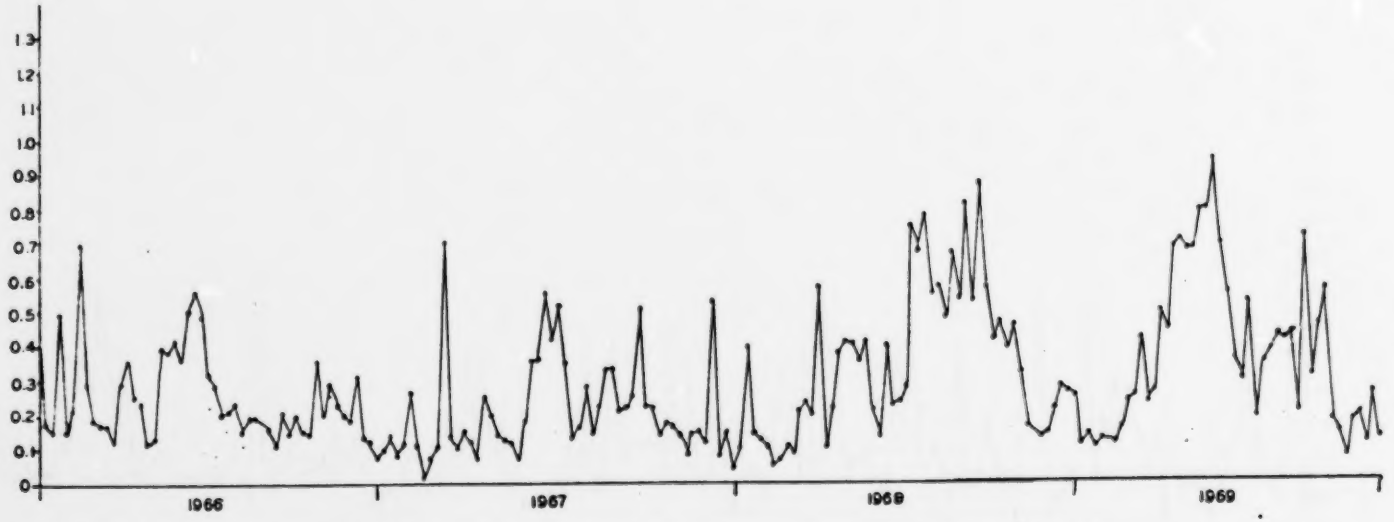

FIGURE 11 (continued): BODs/DO ratio trace, Great Falls Potomac River near Washington, D.C.

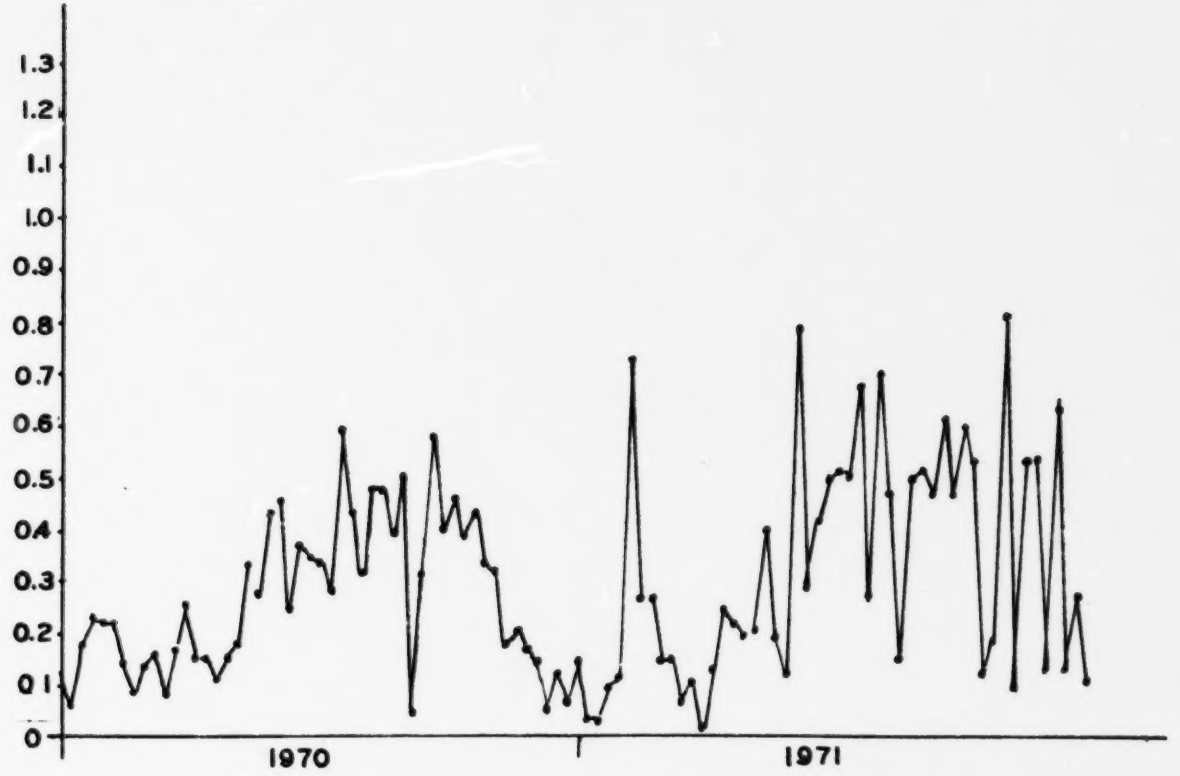

FIGURE II (continued): BODs / DO ratio trace, Great Falls Potomac River near Washington, D.C.

streams. The problem, therefore, seems to be one of excess nutrients derived from both sewage effluents and non-point inputs upstream. Several very low values observed over the period of record are taken as being examples of tannin and lignin inhibition of the BOD curve. These materials are derived, it is believed, from effluents being discharged from pulp and paper mills in the upper watershed near Keyser, West Virginia and Cumberland, Maryland. The tannins and lignins have the effect of delaying the assimilation curve rise so that erroneously low values of BOD are recorded at the termination of a normal five day test.

The basis for assigning a "degraded" label to the stream is the observation of BOD_5/DO ratios in excess of 0.6 and approaching 0.8 in some instances. The level of degradation in the Potomac River is not excessive, however, when compared to those streams where the BOD_5/DO ratio is very much larger than 1.000. AT any rate, a BOD_5/DO ratio of 0.500 with a D.O. content of more than 4.0 mg/l may still be considered a degraded stream in that complete assimulation of the BOD concentration would theoretically lower the D.O. content below the recommended (3) lower limit for flowing streams.

Case F Severely degraded stream

No example of a severely degraded stream is given inasmuch as such streams are readily identifiable by means other than the BOD_5/DO ratio. Candidates for such dubious honors would be the Cuyahoga River at Cleveland, Ohio, River Rouge at Detroit, Morgan Creek near

3) Water Quality Criteria, NTAS, Federal Water Pollution Control Administration, April 1, 1968, Table II-1, p.20.

FIGURE 12: Sample station locations Delaware River Basin Commission

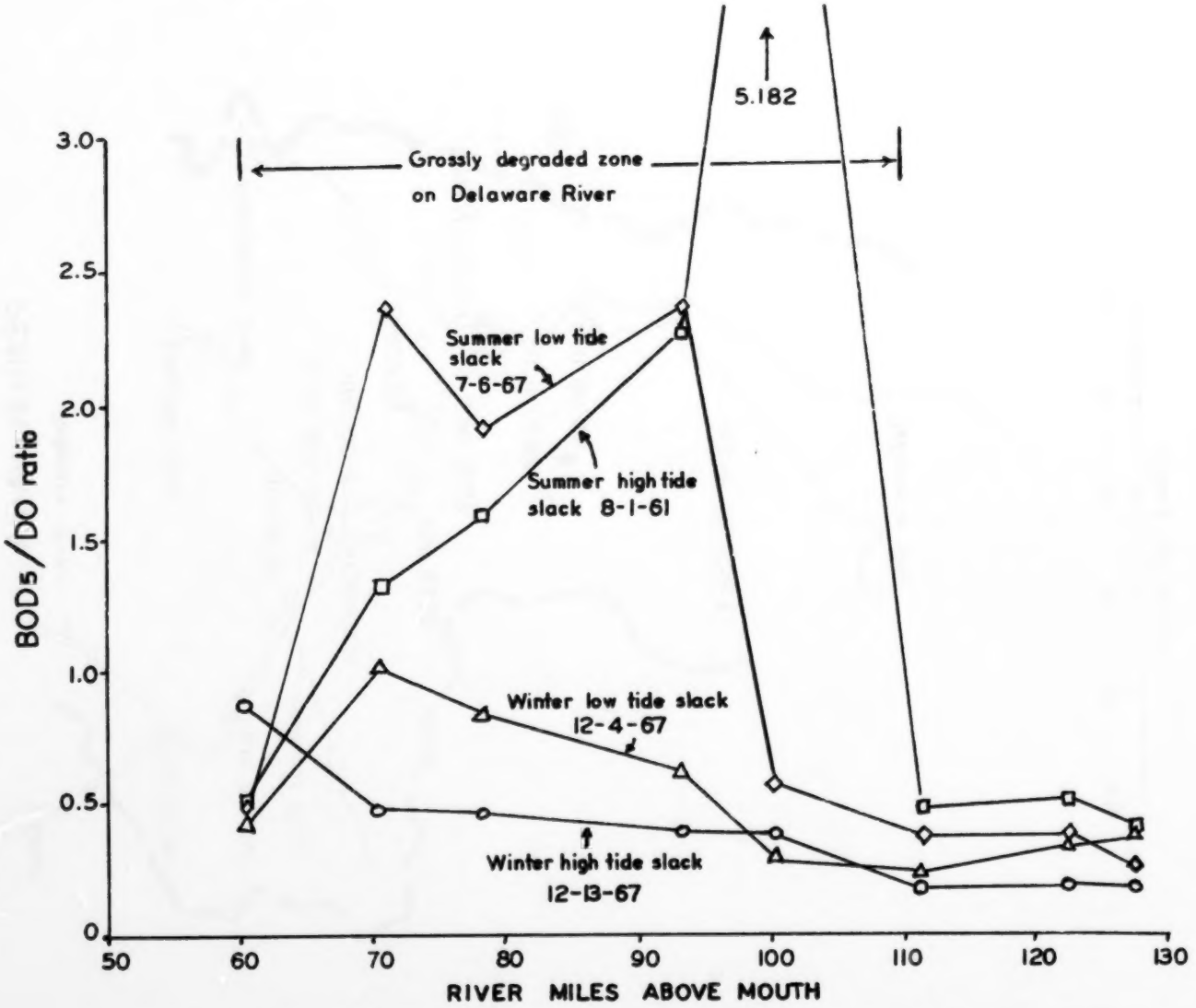

FIGURE 13: BOD5/DO traces Delaware River between Fieldsboro, New Jersey and Pea Patch Island, Delaware

Chapel Hill, North Carolina, South Buffalo Creek at Greensboro, North Carolina and the Lackawanna River at Scranton, Pennsylvania. Criteria for a severely degraded stream would be one in which the D.O. concentration was consistently 1.5 mg/l or less with a BOD of at least 6.5 mg/l. On the biological side, only a few very pollution-tolerant species such as Tubificids, Chironomids and air-breathers such as the pouch snail, Physa, will be present. Under extreme conditions, all macroscopic forms are absent and only bacterial forms, mainly anaerobes, will be found in samples. An example of such a stream would be the Codorus above York, Pennsylvania. In such instances, an occasional macroscopic form may be recovered as an isolated, washed-in individual and not at all representative of the actual ecosystem.

Case G. Fresh-water/estuarine system

Region III contains a number of very large, economically important fresh-water estuarine systems. Among these are the Delaware, Potomac, James, York and Rappahannock estuaries plus Chesapeake Bay. There are also several smaller estuaries on the Virginia-Maryland Eastern Shore. Features such as these are the result of a coastal subsidence inundating river valleys adjacent to the sea. (Figure 12)

Although the estuarine system is a transition zone between fresh and saline water, the BOD_5/DO ratio holds as shown in Figure 13. The curve begins with essentially near-normal stream conditions at

Fieldsboro, New Jersey, shows degradation at the Philadelphia/ Camden section and then recovery at the Pea Patch Island section. The curve also shows the net effect of the Philadelphia and Camden sanitary treatment plant effluents at River Mile 103.96 and 97.88. During the summer months, this effect is noticed almost immediately in downstream stations but winter conditions inhibit the biological assimilation rate (low temperature effects) and the maximum effluent loading point occurs much further downstream. The loading effect is concentrated by resistance to stream flow generated by high tide as shown in the summer high tide slack curve. In addition, the larger relative volume of water available during high tide allows more dilution of river water, hence a better quality of water is observed. During low tide slack, the stream behaves more normally and the assimilation effects are noted much further downstream. It is interesting to note that the Delaware River is only moderately degraded at the Fieldsboro, New Jersey station (River mile 127.48) and that assimilation of biochemical oxygen demanding material from the Philadelphia area is nearly complete at Pea Patch Island (River Mile 60.55). Use of the BOD_5/DO ratio, therefore, serves as a very rapid means of assessing the relative health of any given section of a stream as well as to detect any subtle changes occurring with time. Further, the Delaware River curves show the relative stability

of the better water quality stations (Stations 127.48, 122.49, 100.15 and 60.55) while the degraded sections during the year show much greater fluctuations and instability of the BOD_5/DO ratio.

Case H Specialized uses

In this category, the ratio can be applied to sanitary treatment plant effluents to determine operational efficiency of the unit. Such a test, of course, cannot be applied to a primary plant but a secondary plant, if operating at an optimum level, should produce effluent in which the BOD_5/DO ratio lies between 0.6 and 0.8. Operator's manuals for such plants recommend a 5-day BOD value which is 0.7 of the ultimate BOD figure. Therefore, if the BOD_5/DO ratio is boserved to be 0.6 and 0.8, the net carbonaceous portion of the BOD loading effect of treatment plant effluent upon the receiving stream is nearly zero. If the ratio between effluent and receiving stream is small (small discharge, large stream) then the sum total of the plant operation is for practical purposes, achieving zero discharges insofar as the stream is concerned.

VI. Stream classification using the BOD_5/DO ratio

Assignment of stream pollution categories by means of the BOD_5/DO ratio can be achieved in a general way provided a sufficient backlog of data points is available and the analyses are reasonably free from error.

The preliminary assignment of a stream classification based upon the BOD_5/DO ratio is given in Figure 14.

This classification system, if refined by using a species diversity index of the Shannon-Weiner type, can be used to assign a stream to a meaningful spot in the environmental scale of viability. Values obtained in this study indicate a stream to be nutrient deficient, under winter conditions or having some interference with the BOD test if the ratio falls below 0.075 for any extended period of sampling. The normal stream ratio value seems to lie between 0.075 and 0.300. Degradation begins to be observed between 0.3 and 0.5 and polluted conditions occur between 0.5 and 0.65. Values consistently over 0.65 are seen in grossly polluted streams.

It must be kept in mind, however, that this scale is gradational and the classification given above is considered a working approximation which may require some modification as more work on ratios is carried out. One can say with certainty, nontheless, that any stream with a BOD_5/DO ratio consistently around 0.8 is a stream with a very real problem and in need of immediate remedial action.

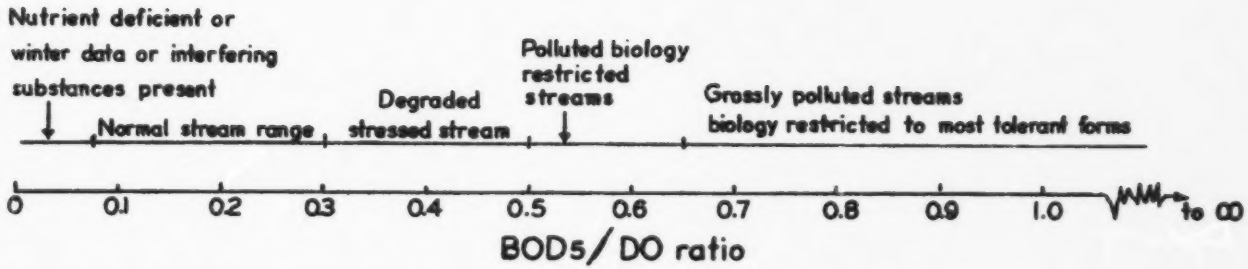

FIGURE 14: Preliminary stream classification based on long-term average values of BOD5/DO ratio

VII. Example of computer program for retrieval of STORET BOD_5/DO data and ratio calculation

The program to extract, calculate and print the BOD_5/DO values and ratio from the various station data stored in STORET is given in Appendix A. This program will allow the data retrieval and calculation of the ratio between BOD_5 and DO for any given station. The program is entered in the STORET system as FORT GCG and the statistical linear regression package to determine the slope of the line through the data points is called REG. This canned program can be accessed by writing CALL REG at the proper location at the beginning of the program.

Summary

The BOD_5/DO ratio has been shown to be useful in evaluating the general health of streams in a variety of settings and conditions. Keeping in mind that a stream is a dynamic, quasi-living organism under the influence of a large number of ever-changing factors, then the value of acquiring a key to determine and understand these changes will be appreciated.

Assignment of rating scale of ratios to streams can assist workers in the water pollution field to understand the actual reaction of a stream to clean-up efforts as well as to monitor any progressive changes being imposed by man-made pollution sources. Data presented indicate the ratio works well in differing stream types in many areas of the county and can be used to evaluate the net ecological activity in these streams. It can also be shown that streams exhibit varying ratios with both time and season but those streams which are relatively clean exhibit only minor fluctuations about a central mode. Conversely, streams which are degraded show a much larger fluctuation amplitude and the BOD_5/DO trace is generally erratic.

Evaluation of the long-term trend slope of the ratio trace will give a good indication of the net effect of pollution-abatement efforts in a watershed or, conversely, determine if a stream is actually in need of a pollution abatement program.

The result of this study is to show that an evaluation tool for understanding one facet of a stream system has been developed. However, additional analyses of stored water quality data as well as new data being obtained today may show that some modification of the classification system will be required. Because of the basic simplicity of the two parameters involved in this ratio, a large number of workers may find this determination useful in the course of their own studies and therefore benefit the general environmental pollution abatement effort.

Appendix A. BODs/DO ratio program with least squares linear regression analysis.

How to Obtain BOD_5/DO Data for Input into Ratio Program

Using the STORET system RET package, the type of retrieval must be a PGM = PUNCH for the data input must be in exponential format. Retrieve the agency, station, BOD_5/DO, dates, etc., using the punch program. Be certain to change (upward) the cards field of the job card; this field is the actual number of cards not thousands as is the lines field.

When the job is awaiting print do not route it to punch, but fetch over your low-speed terminal with fetch xxx ddname Ø (alpha O). Save the data in card or LRECL = 80 format.

Use the data set saved above as the input into the program following.

Important

Retrieve data from STORET in the following sequence:

1. BOD_5 @ 20°C #00310
2. D.O. #00300

Use the computer program included but omit sequence enclosed in brackets if the STORET data is retrieved in the sequence described above. If the STORET data is retrieved as 00300; 00310, then use full program printed.

```
C TO SUPRESS POINT LISTINGS, PLACE A CARD IN FRONT
C     OF DATA WITH 'FAST' IN COLUMNS 1-4.
C FOR JULIAN DATE AND RATIO LIST PLACE A CARD IN FRONT OF DATA
C     WITH 'DATE' IN COLUMNS 1-4.
      INTEGER DATE(6),TIME(2)
      DIMENSION IDSAVE(4),ID(4),
     *KALDAY(12),LEAPYR(12)
      DATA IDFAST/'FAST'/,IDDATE/'DATE'/
      DATA ID/3*'    ',','    '/,SX,SY,SXY,SX2,SY2/5*0./
      DATA KALDAY/0,31,59,90,120,151,181,212,243,273,304,334/
      DATA LEAPYR/52,56,60,64,68,72,76,80,84,88,92,96/
      DATA N,JUMP,LAST,KDATE/4*0/
C ENTER ID VALUE CHANGE
      IST=1
   10 DO 20  LOOP=1,4
   20 IDSAVE(LOOP)=ID(LOOP)
C INPUT A DATA CARD
   30 READ(5,40,END=70)ID,DATE,TIME,BOD,DOVAL
   40 FORMAT(3A4,A3,6A1,2A2,1X,2E8.0)
C
C TEMP REVERSAL OF BOD & DOVAL FIELDS BEGINS
      HOLD=BOD
      BOD=DOVAL
      DOVAL=HOLD
C TEMP REVERSAL OF BOD & DOVAL FIELDS ENDS
C
C CHECK WHETHER JULIAN DATE & RATIO LISTING IS DESIRED
      IF(ID(1).NE.IDDATE)GO TO 44
      KDATE=1
      GO TO 30
C
C CHECK WHETHER POINT LISTING IS DESIRED
   44 IF(ID(1).NE.IDFAST)GO TO 50
      JUMP=1
      GO TO 30
C COMPARE CURRENT ID TO PREVIOUS ID
   50 DO 60  LOOP=1,4
      IF(ID(LOOP).NE.IDSAVE(LOOP))GO TO 80
   60 CONTINUE
      GO TO 170
C
C
   70 LAST=1
C CHANGE OF STATION ID
   80 IF(IST.EQ.1)GO TO 155
   81 REWIND 10
      DO 140  LOOP=1,N
      READ(10,90)KYR,KMO,KDT,RATIO
   90 FORMAT(3I2,F9.4)
C COMPUTE JULIAN DATE
      I=KMO
      JULIAN=KALDAY(I)+KDT
      IF(I.LT.3)GO TO 120
C ADJUST JULIAN DATE FOR LEAP YEAR
      DO 100  I=1,7
      IF(KYR.EQ.LEAPYR(I))GO TO 110
  100 CONTINUE
      GO TO 120
  110 JULIAN=JULIAN+1
  120 JULIAN=1000*KYR+JULIAN
      X=JULIAN
      Y=RATIO
      SX=SX+X
      SY=SY+Y
      SXY=SXY+X*Y
      SX2=SX2+X**2
      SY2=SY2+Y**2
C JULIAN DATE AND BOD-DO VALUES ARE RETAINED
      WRITE(11,130)JULIAN,RATIO
  130 FORMAT(I5,F9.4)
  140 CONTINUE
```

```
C
      IF(N.LT.2)GO TO 153
C FORMULA COMPUTATIONS OF A,B, AND R
      CDEN=N*SX2-SX**2
      IF(CDEN.EQ.0.)GO TO 153
      A=(SY*SX2-SX*SXY)/CDEN
      B=(N*SXY-SX*SY)/CDEN
      DEN2=(SX2-(SX**2/N))*(SY2-(SY**2/N))
      IF(DEN2.EQ.0.)GO TO 153
      DEN=DEN2**0.5
      R=(SXY-((SX*SY)/N))/DEN
C WRITE THE EQUATION FOR THE LEAST SQUARE LINE
C AND THE VALUE OF THE CORRELATION COEFFICIENT
      WRITE(6,150)A,B,R,N
  150 FORMAT(////' Y = ',E13.6,' + ',E13.6,' * X',///' R = ',E13.6,
     *///' N = ',I3,' POINTS')
      IF(KDATE.NE.1)GO TO 153
      WRITE(6,149)
  149 FORMAT(5(/),T32,'JULIAN',T40,'RATIO',/T33,'DATE',//)
      REWIND 11
      DO 1500  LOOP=1,N
      READ(11,151)JULIAN,RATIO
  151 FORMAT(I5,F9.4)
      WRITE(6,152)JULIAN,RATIO
  152 FORMAT(T31,I5,T45,F7.2)
 1500 CONTINUE
C FUTURE PLOTTER CALLS WILL APPEAR HERE
  153 IF(LAST.EQ.1)GO TO 220
      REWIND 10
      REWIND 11
C
C
C CLEAR VARIABLES
      N=0
      SX=0
      SY=0
      SXY=0
      SX2=0
      SY2=0
C WRITE HEADING
  155 WRITE(6,160)ID
  160 FORMAT(1H1,6(/),T27,'SAMPLING STATION IDENTIFICATION NUMBER   ',
     *3A4,A3,3(/),T21,'SAMPLE COLLECTION',T51,'PARAMETERS',T74,'BOD-DO',
     */T24,'DATE',T32,'TIME',T48,'BOD',T61,'DO',T75,'RATIO',/T23,
     *'YYMMDD',T32,'HHMM',T48,'MG/L',T60,'MG/L',3(/))
C
C
C CURRENT ID AND PREVIOUS ID EQUAL
  170 IF(DOVAL.EQ.9999.*10.**(-25))GO TO 215
      IF(BOD.EQ.9999.*10.**(-25))GO TO 215
      IF(DOVAL.NE.0.0)GO TO 180
      RATIO=9999.9999
      GO TO 190
  180 RATIO=BOD/DOVAL
C LOAD WORK FILE
  190 WRITE(10,200)DATE,RATIO
  200 FORMAT(6A1,F9.4)
C INCREMENT N
      N=N+1
      IF(JUMP.EQ.1)GO TO 215
      WRITE(6,210)DATE,TIME,BOD,DOVAL,RATIO
  210 FORMAT(22X,6A1,3X,2A2,4X,2(4X,F7.2,'0'),8X,F8.3)
  215 IST=0
      GO TO 10
  220 STOP
      END
?
```